INFLUENCE OF AGE ON THE RELIABILITY OF HIGH VOLTAGE EQUIPMENT

on behalf of WG A3.06**

SUMMARY
CIGRÉ WG A3.06 is undertaking a survey of reliability and failures of high voltage equipment in service. The time period covered by the survey is 2004 - 2007, and the equipment types under consideration are circuit breakers, disconnectors/earthing switches, instrument transformers and gas insulated substations. The information collected so far has been examined with the purpose of assessing the effect of age, or more precisely: the year of manufacture, on the failure characteristics. It appears that single pressure SF₆ circuit breakers manufactured after 1994 shows only a slightly lower major failure rate than older ones. Thus, puffer breakers of the first generation appear not to have reached the end of their service life yet. The major failure rates for disconnector and earthing switches are strongly correlated with age. Equipment more than 30 years old have failure rates that are around five to ten times higher than recently installed equipment. Instrument transformers failure rates generally show little correlation with year of installation. However, one exception exists; old capacitive voltage transformers have a higher failure rate. Gas insulated substations manufactured after 1994 have substantially lower major failure rates than those manufactured earlier. Quantitative results and more detailed assessments will be available after the survey has been completed and all the collected information has been analysed.

KEYWORDS
High voltage apparatus - Failure statistics - Aging - Service experience

1. INTRODUCTION
CIGRÉ WG A3.06 is undertaking a survey of reliability and failures of high voltage equipment in service. The survey covers failures occurring in the time period 2004 - 2007, and the equipment types under consideration comprise circuit breakers, disconnector switches, earthing switches, instrument transformers...
transformers and gas insulated substations (GIS). The information is collected directly and solely from
the utility sector, and all information is treated as confidential.

The essential features of the survey, including the applied data collection procedures and the
definitions of failures have been described in a previous publication [1]. Some preliminary results, like
information about the equipment populations being surveyed and the failures that have occurred in the
period 2004 - 2005 have also been presented earlier [2].

The present report focuses on an important aspect considered in the survey; the age of the equipment
and the influence of age on the failure rates and types. The age distributions of the equipment
populations covered by the study are discussed, and qualitative trends in failure rates related to age,
wear and maintenance status of the equipment are considered.

For disconnector/earthing switches, and instrument transformers the survey covers all types of
equipment in service, irrespective of age. For circuit breakers there is a limitation to single pressure
SF₆ designs. Therefore, the oldest circuit breakers covered by the study are about 30 - 35 years old.
This is also the case for GIS. Consequently, at least for disconnector/earthing switches and instrument
transformers, equipment approaching the end of its service life is included.

It is however; very important to recognize that correct aging analysis requires that equipment be
surveyed throughout the whole aging period, and that the analysis include only similar designs of the
same manufacturer. Determining age impacts by comparing failure rates of for example of five years
old and 25 year old circuit breakers with basis in failures occurring in the period 2004 - 2007 is not
totally accurate. The now 25 year old breakers did not necessarily have the same failure rate at the age
of five (i.e., 20 years ago) as the five years old breakers have today. Or, in other words, developments
in technical designs, quality assurance practices, maintenance procedures etc. over these 20 years are
very likely to have an affect on breaker failure rates. Consequently, the discussions of age impact on
reliability that follow should be considered with this in mind and recognize they only suggest aging
trends in reliability.

The survey results are presented for one component type at the time. Only qualitative and relative
results are given. Quantitative results, e.g. absolute failure rates, will be provided when all the
available information have been compiled and been through careful quality assurance procedures.

2. CIRCUIT BREAKERS

Up to now 122,650 circuit breaker years of service is included in the survey. This is substantially more
than the approximately 71,000 circuit breaker years covered by the previous CIGRÉ circuit breaker
survey [3]. One dominant country accounts for about 45 % of the population. Much larger populations
have been collected for 2004 and 2005 than for 2006 and 2007, so a realistic goal is to end up with
some 200,000 circuit breaker years of service. Fig. 1 shows the age distribution and also the
distribution grouped according the operating mechanism used.

![Fig. 1. Surveyed circuit breaker service experience segmented after year of manufacture (left) and
after type of operating mechanism (right).](image-url)
For single pressure SF₆ circuit breakers installed before 1984 pneumatic operating mechanisms are most common, but after that a very evident shift towards spring drives is observed.

Fig. 2 shows the circuit breaker major failure rates for old (manufactured before 1984), middle aged (manufactured in the period 1984 - 1993) and new ones (manufactured after 1993).

Equipment year of manufacture appears to play a role; the failure rate is lower for the newer circuit breakers. However, the difference is modest, and the first generation SF₆ single pressure circuit breakers are still quite reliable compared to more recent generations.

More details concerning the major failures and the influence of the circuit breaker manufacturing year are given in Fig. 3. The left graph shows the most frequently occurring failure modes, whereas the right shows the failures segmented by which circuit breaker sub-component that fails.

It appears that “Fails to perform requested operation” and “Locking” are the most common modes both for old and new breakers. (A breaker that does not open/close on command or that opens/closes without command falls with within the first failure mode category, whereas “Locking” means that the breaker is locking in an open/closed position and that an alarm has been triggered by the control system.) Together these failure modes constitute 70 - 80 % of all major failures which is essentially as in the previous survey.

Older circuit breakers seem to have somewhat more problems with the operating mechanism than newer ones, and dielectric breakdown and control circuitry problems constitute a somewhat smaller
fraction of the collected failures as age increases. However, none of these represent very obvious age-related trends with regard to failure modes and failing sub-components. Again, it seems reasonable to conclude that most single pressure SF$_6$ circuit breakers not yet have reached their end of life condition.

### 3. DISCONNECTORS AND EARTHING SWITCHES

The present survey is the first broad international reliability survey on disconnectors and earthing switches. So far, 69 utilities from 24 countries have provided information, totalling more than 500,000 years of surveyed service experience. Fig. 4 shows how this distributes in component age and type.

![Fig. 4. Disconnector/earthing switch surveyed service experience sorted after year of manufacture and type. (AIS: air insulated substation.)](image)

It can be seen that for the youngest switches the GIS part is increasing. This is also influenced by the fact that almost 50% of all information comes from one dominating country with a large GIS population. More than half of the AIS switches surveyed are more than 20 years old.

As opposed to circuit breakers, disconnectors and earthing switches show a very distinct variation in failure rate with year of manufacture, see Fig. 5. New switches are much more reliable than old ones.

![Fig. 5. Major failure rates for the various types of disconnector and earthing switches vs. year of manufacture.](image)

The operating mechanism is a very important part of disconnectors and earthing switches as it is the subject of a large part of the maintenance efforts and still found to be responsible for around 42% of the major failures recorded. Fig. 6 shows the failure rates for the dominating four types of drives.
The failure rates differ substantially among the different types of operating mechanisms, and again, there is a distinct correlation between drive failure rate and age. The oldest equipment is less reliable than that being manufactured more recently. For pneumatic drives however, a small reduction in the failure rate is observed for the oldest equipment. This may be a result of major maintenance efforts or complete overhaul of the pneumatic system after some 25 - 30 years in service.

4. INSTRUMENT TRANSFORMERS

Instrument transformers are, unlike the other component types, counted in single phase units. Fig. 7 shows the surveyed service experience. More than 600,000 unit-years are up to now included, of which nearly half is GIS equipment.

The left graph of Fig. 8 shows the overall failure rates for GIS and AIS instrument transformers, respectively. The most striking observation is the much lower failure rate for equipment installed in GIS. Age does not appear to be a significant reliability factor on GIS instrument transformers.

The right graph of Fig. 8 shows no clear effect of the year of installation for the reliability of AIS equipment. Current transformers appear to have an increased failure rate with age but it is not clear that this result is statistically significant comparing the results of the other types of instrument transformers.
Fig. 8. Overall instrument transformer major failure rate (left) and AIS CT, CVT and MVT major failure rates (right); both as a function of year of manufacture.

Fig. 9 shows the distribution with regard to which part of the instrument transformer that fails. The main internal insulation causes the highest proportion of failures although the proportion reduces for newer equipment. It is not clear if this is due to an aging effect, an improvement in main insulation for newer equipment or a change in the population over time (such as increased use of GIS).

Fig. 9. Instrument transformer major failures segmented by failing sub-component and year of manufacture.

5. GAS INSULATED SUBSTATIONS

So far 53 utilities from 22 countries have contributed with information about their GIS populations and associated failures. Fig. 10 shows how the surveyed service experience distributes with regard to year of manufacture. One dominant country has provided about 67% of this population data. As can be seen, around half of the equipment considered is manufactured after 1994.
Fig. 10. GIS surveyed service experience sorted after equipment year of manufacture.

Fig. 11 shows GIS major failures rates as a function of year of manufacture and segmented by voltage level and whether the GIS is installed indoor or outdoor.

Several preliminary trends emerge from these graphs. First, the major failure rates for GIS installed outdoor is 2 - 3 times higher than for those installed indoor. Second, both indoor and outdoor GIS show a clear correlation between failure rate and year of installation. Old GIS, i.e., those from before 1984 have roughly 4 - 5 times higher risk for suffering a major failure than the youngest group.

Third, the failure rate differs greatly between the voltage levels. The highest failure rates for older populations are seen in the voltage ranges 100 - 200 kV and 300 - 500 kV which both are dominated by European utilities. Equipment in the voltage range 200 - 300 kV shows a slightly lower failure rate for the oldest equipment. This may possibly be explained by different technologies, maintenance practices, design margins, etc.

The distribution (segmenting) of the major failures between the different components of the GIS for the various ages is shown in Fig. 12.
The most significant finding from Fig. 12 is that GIS parts other than switching equipment and instrument transformers constitute an increasing fraction of the major failures. Busbars, bus ducts, bushings etc. account for one third of the major failures of equipment manufactured in the period 1994 - 2005.

6. DISCUSSION AND CONCLUSIONS

Information about reliability and failures collected by CIGRÉ WG A3.06 has been examined with the purpose of assessing the effect of age, or more precisely: the year of manufacture, on failure characteristics for high voltage equipment. Among the findings are:

- Single pressure SF₆ circuit breakers manufactured after 1994 show only a slightly lower major failure rate than older ones. Thus, puffer breakers of the first generation appear not to have reached the end of their service life yet. Likewise, newer generation SF₆ circuit breakers manufactured after 1994 do not show any infant mortality problems.
- The major failure rates for disconnector and earthing switches correlate strongly with age. Equipment more than 30 years old have failure rates that are around a factor five to ten higher than recently installed equipment.
- Instrument transformers failure rates generally show little correlation with year of installation. However, one exception exists; old capacitive voltage transformers have a higher failure rate.
- Gas insulated substations manufactured after 1994 have substantially lower major failure rates than those manufactured earlier.

Quantitative results and more detailed assessments will be available after the survey has been completed and all the collected information has been analysed.

7. BIBLIOGRAPHY